NEXT GENERATION HIGH-SPEED RAIL

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The Next Generation High-Speed Rail Support Program began in December 1994 in response to the Swift Rail Development Act of 1994 and the Federal Railroad Safety Authorization Act of 1994. The objective of the Next Generation program is to support the availability of modern, cost-effective technology enabling rail passenger service at speeds up to 150 mph on existing infrastructure. The Swift Rail Development Act of 1994 authorized the FRA to sponsor research and demonstrations to improve safety by reducing human and technological failures, enhance revenue generation capabilities through customer service upgrade measures such as shorter trip times, and finally, decrease capital and operating costs of high-speed rail service. The focus of the program has been to support this objective by adapting, improving, and demonstrating existing or promising technologies that could have wide application in U. S. corridors. This focus has been re-authorized in the 1998 Transportation Equity Act for the 21st Century.

The program focuses on three main areas: track evaluation, improvement, and maintenance; signaling and communications; and non-electric motive power. Two important issues, grade crossing risk mitigation and capacity enhancement, bridge the track improvement area and the signaling and communications area. These areas have been selected to address the major cost elements inhibiting the introduction of high-speed service. In addition, the program is developing technology improvements directed at ensuring safe high-speed operations while reducing maintenance costs, improving braking performance and reducing noise and other environmental impacts.

TRACK EVALUATION, IMPROVEMENT, AND MAINTENANCE

A major cost barrier to the introduction of high-speed service is the need to upgrade existing track structures to a level of uniformity and quality appropriate for high-speed operations. This often involves a significant improvement in the underlying track structure as well as improvements in rail and track geometry. Initial service will be over track shared with freight operations and the track must be maintained to support both levels of track loading. Efforts in this area are concentrating on reducing the cost of track structural evaluations and identifying specific techniques that can effectively improve the underlying track structure. Turnouts, grade crossings and bridges are traditionally areas where the abrupt change in vertical and lateral stiffness result in accelerated rates of track geometry degradation. The FRA has initiated studies into methodologies for reducing the magnitudes of the variations by placing specially designed elastomeric pads between the rail and the tie plates in the region of the transition. Early results show that vertical accelerations were significantly reduced near a bridge transition on the northeast corridor. Further studies are required to determine the long-term effectiveness of these treatments and whether the pads will withstand the harsh environment.

Track inspection is a major expense in maintaining high-speed track. Traditionally, track geometry measurements have been used to identify track requiring major maintenance activities. As track occupancy time becomes scarcer the need to identify the exact nature and location of the track irregularity and the most appropriate maintenance procedure becomes more critical. In addition, many operators of high-speed track use acceleration data from revenue trains to help anticipate track problems before they become safety critical. These systems can be used effectively to monitor both track and equipment but are still in the developmental stages. Enabling technologies for these systems are low cost computer and signal processing equipment, global positioning systems (GPS), and wireless communications. Perhaps the most important feature of these systems is the ability to collect data without human intervention, the major cost in track geometry inspection. The GPS or differential GPS (DGPS) systems help pinpoint the subtle track geometry defects that can cause rapid deterioration of the underlying track structure when supporting both heavy freight and high speed passenger equipment.

Other areas of interest, although with no currently active projects, are high-speed turnouts, internal rail flaw inspection, and the importance of concrete versus wood ties in maintaining high-speed track stability. In anticipation of these projects the FRA has built two state-of-the-art instrumented wheelsets capable of accurately measuring the wheel rail forces resulting from track irregularities and special features such as guard rails and flange supported frogs.

SIGNALING AND COMMUNICATION IMPROVEMENTS

Since 1994, the FRA, in partnership with state agencies, has sponsored three separate initiatives in the area of train control with the objective of demonstrating cost-effective systems capable of providing the safety similar to traditional communications and signal systems, and the business benefits of positive train control (PTC). These three initiatives are **Incremental Train Control, Advanced Train Control, and Positive Train Separation**.

Traditional Communications and Signaling Systems

Traditional communications and signaling (C&S) systems are all reliant on relay-based track circuits. The four types are non-coded and coded AC and DC track circuits. These track circuits are the fundamental building block of fixed block train control systems such as Automatic Block Signaling (ABS), Centralized Train Control (CTC), Direct Traffic Control, and Cab Signaling. These systems are expensive to install and maintain due to the large number of components required. They are reliant on an extensive wayside equipment and circuit infrastructure including semaphores, relay huts, and ground circuits that operate the track circuits and the interlockings.

The Advanced Civil Speed Enforcement System (ACSES), currently under development for the NEC, is an example of a fixed block train control system that is being augmented for high-speed passenger service. This system is based on a wayside transponder network that will communicate with an onboard locomotive radio system. The transponders will transmit civil speed restrictions of either an entire or partial block to a locomotive's onboard computer. The onboard computer will convert this information to a cab signal for the engineer. The onboard computer will also compare the speed restriction with the actual speed of the locomotive to determine if the speed is in violation of the restriction. If a violation is occurring, the system's enforcement control will be activated. This will entail bringing the train to a complete halt, also known as positive stop. Initially the ACSES will be installed between New Haven, Connecticut and Trenton, New Jersey. Eventually, the system will be extended to the entire Boston to Washington corridor. The system is being developed by GEC Alstom.

The ACSES will migrate the NEC from the present four-aspect continuous cab signal system to a nine-aspect continuous cab signal/speed control system. The ACSES will provide for train operations up to 150 mph with intermediate speeds of 125, 100, 80, 60, 45, and 30 mph as well as positive stop. This system is currently being tested and refined on a test bed near Philadelphia, Pennsylvania.

Current Communications-Based Train Control Pilot Programs

In order to increase safety, operating capacity, and efficiency, railroads and railroad suppliers have instituted pilot concurrent communications-based train control (CBTC) projects. These projects demonstrate the safety and economic benefits of employing modern communications and control systems toward the implementation of moving train control systems. Some of these projects are listed below.

Incremental Train Control - The Michigan Incremental Train Control System (ITCS) is a joint venture between the Michigan Department of Transportation (MDOT) and Amtrak. The signaling supplier is Harmon Industries. The system is a distributed wayside-based system that is designed to function as an overlay to the existing coded track circuit system. The backbone of the system is a wayside local area network (WLAN) consisting of wayside interface unit (WIU) servers spaced every 2-6 miles. Each WIU server communicates with 5-10 WIU nodes. These nodes monitor the existing track circuitry system and report current track circuit, signal aspects, switch positions, and public grade crossing information as they are polled by the WIU servers. This information is communicated to the Office System by means of the WIU servers. All movement authorities, temporary slow orders, and switch control information originate from the Office System and are transmitted to the wayside via a modem-wire line-modem communications link.

Advanced Train Control - The Illinois Positive Train Control System was originally a joint venture between the Illinois Department of Transportation (IDOT), and the Southern Pacific (SP) Railroad, with Canac International as the system integrator. The intent was to select a supplier to install a transponder-based, high-speed train control (PTC) system on a segment of the SP between St. Louis, Missouri and Chicago, Illinois. Following the merger of the Union Pacific (UP) and SP Railroads, the project was somewhat delayed as the railroad evaluated the objectives of the program and the long-term plans for the track involved. The important goal of a demonstration of a full-featured, centralized, safety-critical communication-based train control system remains. The AAR has joined with the goal of encouraging interoperability.

Positive Train Separation - The Burlington Northern Sante Fe and Union Pacific have been developing a PTS System. This demonstration project is being deployed by GE-Harris in the Pacific Northwest between Seattle and Pasco, Washington, and Portland, Oregon. The project participants are the Washington State Department of Transportation, Oregon State Department of Transportation, BNSF, UP, and Amtrak. The PTS system is a non-vital overlay that will operate in conjunction with the existing track circuitry system. The system is comprised of three fundamental components: (1) the centrally located server system, (2) the communications system, and (3) the onboard locomotive system. The communications system consists of a network of cables, microwave links, fiber optic cable links, and telephone circuits. This system is employed to transmit authority limits and speed limits established by the server system to the PTS equipment located onboard the locomotive as well as transmit train location information to the server system.

The major product of the demonstration is the system software and network management protocols that were developed. In addition, a number of system reliability issues can be resolved. The railroads will utilize the performance data collected during the demonstration project for deployment of potentially vital PTC systems over large segments of both railroads. Since this is a joint project, there is a significant degree of interoperability between the two railroads. This should improve the cost effectiveness of any future PTC installations. A significant incentive for developing this system was to enhance the capacity of this heavily-used track. The FRA joined the project to help assess the potential capacity improvements afforded by an advanced train control system. GE-Harris, Inc., with a funding grant from the FRA, developed a dispatching simulator for the BNSF/UP PTS system in Washington. This simulator was used to evaluate the potential benefits of adding centralized train control and more important, traffic control to the region.

Locomotive Onboard Communication Platforms

The locomotive onboard computer systems, in addition to performing functions as train overspeed protection, are required to communicate with locomotive propulsion systems and electronically controlled pneumatic braking systems, and monitor locomotive health. The key element of onboard communications is the networking protocol linking the components. Several industry protocols that have been the subject of recent evaluation are Lontalk IEEE 1473.1, Ethernet IEEE 802.3, and Token Ring IEEE 802.5. The Conrail, NS, and CSX design team has recently chosen Lontalk IEEE 1473.1 as the onboard platform protocol in their recently released design. This protocol was chosen based on its reliability, availability, and maintainability characteristics. This is a significant step forward in the industry-wide effort for an open architecture, interoperatable protocol given that Lontalk IEEE 1473.1 is employed in many of the ECP systems currently under test.

Future Plans

As these demonstration projects and enabling technologies mature, the FRA, railroads, and suppliers will continuously monitor the lessons learned. The value of systems will be determined, from both safety and capacity enhancement.

GRADE CROSSING RISK MITIGATION

Highway-Rail Grade Crossing safety is a major program area in Improving Safety. Grade crossings and the associated risk are also a major impediment to the introduction of higher-speed passenger rail service. In many of the corridors, highways cross the existing tracks more often than once per mile. A full grade separation may cost as much as $2 million and grade crossing closure is often not an acceptable option from a local traffic planning perspective. While the risk to the highway user is not a strong function of train speed, the increased frequency of trains often associated with a new service introduction could substantially increase accident rates. In addition, the risk to passengers and train personnel, while small, does increase as the speed increases. The FRA has identified grade crossing risk mitigation as an important area for safety research and the next generation program has identified candidate technologies and innovative approaches to warning highway operators of approaching trains, and warning train operators of highway vehicles stalled or stuck at crossings. The Harmon Industries Incremental Train Control project in Michigan includes a demonstration of a prestart health and monitoring capability using radio communications links between the locomotive and the grade crossing. The system would alert the train personnel of the crossings functionality allowing the train to slow down prior to reaching the crossing. In addition, the system starts the crossing warning devices by radio communications link, without depending on the traditional track circuits that were deployed appropriately for slower freight trains. It is an important requirement that warning devices start within a set time prior to the arrival of a train.

In another demonstration, the FRA has worked with the state of Illinois on the deployment of an 'arrester net' project. In this application, possibly appropriate for very high risk crossings, the highway approach is equipped with a special net capable of safely stopping even heavy highway trucks from fouling the crossings while a train is approaching.

In New York and Washington, work has proceeded on the development of a special crossing appropriate for very low density private crossings. In the Michigan Corridor as well as in other corridors, there are a number of private driveways across the tracks. One idea is to have locked gates where individuals could request that the gate open, and for which the control system would automatically determine if any trains were in the area, and open the gate, if appropriate.

Finally, the FRA has been working with Florida to develop a low cost bridge for low traffic density crossings where the local traffic patterns could allow reduced clearances. No site has yet been identified to deploy this technology.

In a related area, the FRA has developed a methodology for assessing the relative risk of various crossings in a corridor and is currently developing data on the effectiveness of new warning devices such as four quadrant gates and median barriers. These are important in assessing the actual risk posed by a change in operating frequencies and speeds. In addition, the FRA is pursuing systems that could improve the reliability of crossing systems and reduce the cost of introducing even simple active warning devices. Likewise, the FRA is studying the possible implications of traffic patterns and vehicle types on the estimates of risk. Here the implications of high traffic counts or concentrations of heavy trucks during a few periods during the day could reduce the average risk, if there were no planned trains during these periods. Conversely, if day averages are used, risks may be underestimated when high traffic counts and high train traffic coincide, such as near rush hour.

NON-ELECTRIC LOCOMOTIVES

High-speed passenger rail initiatives are being considered in many corridors around the country. Most of these are not currently electrified and do not anticipate traffic densities sufficiently large to justify the capital expense of an electrification system. In order to attract ridership, these proposed services must offer competitive trip times and ticket prices. In many of these corridors the target maximum operating speed needs to be increased to between 125 and 150 mph. In addition, acceleration capabilities similar to the performance achieved with electrified trains is required to maintain high average speeds after slowing down for curves or station stops.

Almost as important as rated speed and acceleration capability, is axle load. High-speed trains must have low axle loads to reduce the damage done to the track structure at high speed. The locomotive must also be lightweight to reduce the track forces and to reduce the power requirements needed to accelerate after station stops or small radius curves. Here the goal is to limit the axle load to less than 25 tons. A typical freight locomotive has an axle load of 33 tons or more.

At the present time there are few non-electric locomotive alternatives to providing power for high-speed trains. The most common practice in the U.S. has been to take a basic locomotive designed for freight operations and to change some of the attributes such as the gearing, power conditioning and in some cases the power console. Examples of these are the P-40, P-42, F-59, and the older F-40. These locomotives have an axle load of approximately 33 tons and top speeds around 100 to 110 mph. These are all large displacement diesel engine powered locomotives that can be purchased and operated at very low cost. Nevertheless, their dynamic performance at increasing speeds has often been a limiting factor when pulling advanced tilting passenger equipment. These locomotives also have a large cross-sectional area compared to high-speed electric locomotives, greatly increasing the aerodynamic drag further and limiting their effective top speed.

Gas Turbine Engines

An alternative to large displacement diesel engines is a gas turbine. The first versions of the Train á Grande Vitesse, the French TGV trains, were powered with gas turbines. Several gas turbine trainsets have been used in the U.S. since the late 60's. The Rohr Turbo Liner (RTL) trains operating on the Empire Corridor in New York State are powered with very small, lightweight gas turbines. The challenge has been that the gas turbines used have been seen as expensive to operate, primarily from a maintenance and fuel consumption perspective. The problems of maintenance costs may have been largely solved with the evolution of gas turbine power for military applications and non-railroad related commercial development, most notably, for marine and aviation. A remaining problem is the fuel consumption, particularly at idle, and the variation in the power duty cycle.

Diesel Multiple-Units

The second alternative is the diesel multiple-unit which is very popular in Europe for operations up to about 100 to 125 mph. These trains essentially have no locomotive. Many of the cars in a train are equipped with diesel engines mounted below the floor of the passenger compartment. Each engine then supplies power either electrically or hydraulically to motors mounted on one or more axles of the car. A common arrangement is to have half the cars carrying engines and half the axles being powered. The primary advantage in this arrangement is that the weight of the engines is distributed throughout the train, thereby reducing the axle load. The main disadvantage is that the distributed engines are more expensive to maintain and the train arrangement makes the design of the passenger cars more difficult. There is also an issue of crash energy management that becomes important as speeds increase.

Initiative of the Next Generation High-Speed Rail Program

The FRA has determined that none of these approaches fully satisfies the difficult demands of high-speed passenger rail operations in U.S. corridors, and it has developed an intensive program to develop a nonelectric, lightweight, high-powered locomotive. The approach is twofold: to upgrade the existing Empire Corridor turbo train fleet and to demonstrate a truly high-performance, next generation, non-electric locomotive.

RTL Upgrade on the Empire Corridor

The most immediate impact program was the upgrade of the existing Empire Corridor RTL turbo train fleet with higher powered gas turbines while improving the dual mode operating characteristics. These trains are required to operate on third rail power while in the tunnels approaching Pennsylvania Station in New York City. The new engines should reduce the trip time between Albany and New York City to less than 2 hours. This upgrade will not, however, improve some of the acceleration limitations of these trains at low speeds, due to the hydraulic transmission, and at high speeds, due to low peak power.

Flywheel Energy Storage Systems

In 1995, the FRA initiated two efforts to investigate the use of flywheel energy storage devices to help reduce variations in the power duty cycle of high-speed passenger locomotives and to improve the energy efficiency of the trains. The first was an effort with the University of Texas and an industry team, including Argonne National Laboratories, General Motors - ElectroMotive Division, the AAR, Allied Signal Aerospace, Allied Signal Engines, and Avcon to investigate the use of a single large flywheel in combination with a high powered gas turbine to produce a demonstration locomotive capable of performance similar to electric locomotives. The flywheel will store enough energy to nearly double the power capability of the locomotive for up to four minutes, the time required to accelerate to 150 mph. The flywheel will then be recharged with surplus power from the turbine while the train is at cruise speed, and from regenerative braking energy available when the train is slowing down for curves or stations. Preliminary studies indicate that use of the flywheel can reduce the fuel costs by as much as 30 percent compared with a similarly performing conventional turbo train. In these studies, the gas turbine is sized at about 3 MW, the power required to pull four typical passenger coaches at speeds up to 150 mph. The locomotive would require an additional 3 MW for several minutes to accelerate from station stops and slow curves. In addition to the fuel savings, the flywheel should be less costly to maintain as compared to an additional gas turbine.

A number of important enabling technologies make flywheels a potentially viable alternative to installing twice the rated power. The first is the advancements in the design and fabrication of composite flywheels. Using multiple rings of both carbon fiber and fiberglass with modern epoxies, manufacturers can now control and effectively manage the internal stresses within the flywheel. These designs can preclude catastrophic rim failures, making the resulting designs much safer. The next important enabling technology was the maturing of magnetic bearings. These bearings are critical in providing support to the spinning structure at very high speeds with very low losses. Finally, compact, high-power alternators are required to efficiently store and extract the energy for the rotating mass. Large flywheels rotate at speeds up to 15,000 revolutions per minute (rpm)and ideally should be coupled directly to an alternator. Allied Signal has been developing just such an alternator for military applications and has now focused on the flywheel application. A very similar alternator design can be used to generate electrical power when coupled to a gas turbine which normally operates at about 15,000 rpm.

The University of Texas has built two scale model versions of the full size flywheel to investigate details of the manufacturing and assembly process, and tests have shown the design to be even more robust than analysis had predicted. The full scale, 500 to 600 megawatt/second flywheel should be completed in 1998.

The last remaining issue is the integration of the flywheel and gas turbine into a prototype lightweight locomotive with the appropriate traction motors, power conditioning equipment, power inverters, ancillary equipment, and controls. The FRA has issued a request for proposals for a locomotive manufacturer to provide this important system integration.

An alternative to the single large flywheel is being investigated by Morrison Knudsen and the University of Idaho. The idea here is to use multiple, parallel small flywheels to achieve the same energy storage and power capabilities as with the large flywheel. Small flywheel technology is being driven by military, aerospace, transit bus and automotive applications, as well as stationary backup power supply initiatives. These applications may reduce the cost of flywheels and the associated power electronics through economies of scale unlikely to affect the large flywheel designs in the near future. Small flywheels rotate at speeds exceeding 100,000 rpm, requiring specialized motor generators that are generally integrated into the flywheel design. The key element of the parallel designs is the cost and sizing of the individual power inverters required for each flywheel, and if these systems can be effectively controlled to mimic the performance of a single large device. Two significant advantages of the multiple approach are that a single flywheel failure would not have a big effect on the system performance and that problems with gyroscopic effects could be more simply controlled.

Finally, the FRA is monitoring the performance of high-speed diesel engines for applications in diesel multiple units and as lightweight alternatives to traditional large displacement diesel engines typical of freight service. While there are no current active projects attempting to demonstrate this technology, the non-electric locomotive demonstration project is structured to allow a variety of potential power supply configurations.

LIGHTWEIGHT BRAKE MATERIALS

Ideally, both the total vehicle weight and the unsprung mass should be low. The unsprung mass is the mass in contact with the rail without the benefit of a suspension system – typically the axle, wheels, and some portion of the traction motors or disk brakes. For non-powered axles, there are often as many as four cast iron disks per axle used for friction braking. High-speed trains in Europe and Japan have experimented with lower weight steel alloy disks in combination with specially manufactured friction material to achieve longer life and better performance when compared with traditional non-asbestos organic brake pads. Newer materials including special composite material disks may provide similar exceptional performance at greatly reduced weights. The FRA has sponsored investigations into the performance of these new materials compared with existing designs and identified a number of promising friction material combinations. Key issues remaining, such as the cost of manufacturing these components, will ultimately determine their marketability.